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**MILITARY CONTROL SPECIFICATIONS FOR ELECTRON TUBES**

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**JUNE 1954**

**WRIGHT AIR DEVELOPMENT CENTER**

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## MILITARY CONTROL SPECIFICATIONS FOR ELECTRON TUBES

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*June 1954*

Task No. 41651

Wright Air Development Center  
Air Research and Development Command  
United States Air Force  
Wright-Patterson Air Force Base, Ohio

## FOREWORD

This report was prepared by Mr. Walter C. Kirk, special consultant in the Electronic Components Laboratory, Directorate of Research, Wright Air Development Center. The work was administered under Task No. 41651, "Tube Applications Handbook," of Project No. 4156, "Electronic Tubes and Transistors," with Mr. Rex Whitlock acting as project engineer.

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#### ABSTRACT

This report presents an approach to the problem of describing electron tubes for procurement purposes. This procurement is for such electron tubes as required for military applications. Part I covers the practical consideration of the specification and the relation of its content to the military requirement, while Part II covers the technical details necessary for the construction of an adequate specification.

#### PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

*R. E. Loring*  
*for* RICHARD S. CARTER  
Colonel, USAF  
Chief, Electronic Components  
Laboratory  
Directorate of Research

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## INTRODUCTION

The need for specifications which consolidate and maintain the advances made by the various programs, relative to reliable operation of electron tubes in military equipment, resulted in the development of military control specifications. These specifications embody two parts: (1) the rating or requirement section and (2) the compliance or procurement section. The objective of the procurement section is to furnish a specification giving assurance that the items as procured will perform at the rated conditions. The procurement specification, then, is an instrument designed to evaluate tubes for the purpose of acceptance: (1) it describes means of measuring their properties, and (2) it establishes a standard of minimum of acceptable quality in terms of the measured properties.

Military control specifications provide a set of required tests and limits. No methods are included for determining these requirements. They must be determined by other means especially designed for that purpose. Once the properties for the requirement are known, military control specifications provide a method by which the maintenance of such properties to the desired level is assured.

The specifications also provide a means of estimating compliance with a standard of quality on a lot basis. That is, the specification serves as a standard for estimating, regardless of whether the tubes are at the source of manufacture, in the equipment manufacturer's stock, or in military depots. All tests are designed to use methods and procedures which can be performed at any time subsequent to presentation for military acceptance.

All efforts are made to make the specification a practical and workable instrument. It must be easily understood and be readily applied, for example, from the standpoint of the service inspector. Theoretical statistical control must be carefully weighed against practical economic considerations.

Practical estimation of lot properties, rather than virtually impossible absolute determination, is the basis of the sampling procedures used. In these procedures is recognized the fact that as the determined lot per cent defective approaches zero, the number of items required to be tested increases rapidly. The law of diminishing returns establishes the practical economic limit.

The specifications provide, in so far as possible, clear-cut tests and limits for the purposes of establishing the quality levels. They must allow for competition within the electron tube industry and encourage the application of initiative and ingenuity.

## PART I

### GENERAL CONSIDERATIONS FOR SPECIFICATIONS

#### A. Types of Specifications

Inasmuch as specifications provide for the compliance of purposeful particulars and requirements to describe an item, the purpose of the specification will determine the type.

##### 1. Construction Specification

The construction specification describes the materials and processes used in constructing or fabricating an item. Through the use of such a specification, the many processes and materials can be controlled and standardized. This control and standardization is, however, limited or provided for only to the extent of the completeness of the specification itself. Electron tube manufacturers depend on this type of specification for manufacturing controls. Such a specification aids in standardizing the materials and processes thereby resulting in a more uniform product for the manufacturer. The completeness of the knowledge of the controls and processes governs only the degree of effectiveness.

##### 2. Performance Specification

The performance specification describes the item in terms of its particular properties relative to an application. (The completeness of this description in no way alters the classification.) This type of specification can be either the simplest in form or the simplest for evaluation of the product, but rarely both. The simplest form of a performance specification is to specify that the item has those properties required to perform satisfactorily in a specific piece of equipment. Such a specification is to a large extent used by equipment manufacturers of entertainment equipment for electron tube procurement and as such is usually applicable to one manufacturer. A much more complex form of a procurement specification is the list of specific properties describing the item. This form, however, is simple to evaluate the product for compliance. Such a specification is in general use by all electron tube manufacturers for final evaluation of their product. Such a specification is frequently used to supplement the construction specifications by providing a method of determining both non-compliance with, and inadequateness of, the requirements of construction specifications by measuring the characteristics of the article.

##### 3. Procurement Specification

The procurement specification can be either or a combination of both the construction and/or performance specification. As the name implies, such a specification describes an item for procurement purposes. Usually, such a purpose is best served by the performance-type specification.

Irrespective of the type of specification used for procurement purposes, all properties specified must have a means of test available to note compliance with the specifications. By nature, all specifications of electron tubes for the military are procurement specifications.

## B. Specifications for Procurement of Electron Tubes for the Military

### 1. General Considerations for Military Specifications

The military requires the use of the performance-type specification; however, the application problems are greatly increased because such a specification must reflect many more diverse applications than found in most commercial applications. This complication results from the methods that must be used in governmental procurement. It is not the purpose here to attempt to evaluate the procurement system; it can only be said that means must be established to assure the most effective operation of such a system in regard to the procurement of electron tubes.

An analogy between commercial procurement and military procurement may be drawn by viewing the situation that arose in regard to a gasoline engine driven-type washing machine. In equipping the machines the private industry operator investigated the various type engines and found that manufacturer A supplied an engine of one horsepower, name-plate rating, at \$45.00 that performed excellently both initially and for the desired time. Manufacturer B decided to attempt to get the engine business. A sample of his one-horsepower engine was supplied. The price was \$40.00 and the name-plate rating was the same as manufacturer A, but the engine would not drive the washing machine satisfactorily. In defense of his position, manufacturer B presented test data showing his engine was one horsepower and would deliver its rating continuously for a long time and suggested that a higher horsepower rating was required. The washing machine organization was unimpressed--the engine did not perform, therefore, procurement continued from manufacturer A.

The requirements for the engine were rather well defined. It must satisfactorily operate the washing machine. Cost was another matter--irrespective of such cost unsatisfactory performance could not be tolerated.

Continuing the analogy, suppose, for some reason the washing machines were being sold to residents of a municipality by their government. Supply sources in this case were to be determined by competitive bidding. The washing machine specifications required an engine of one horsepower. Bids were received on an engine specification of one horsepower. Manufacturers A and B both placed bids. Manufacturer B was awarded the contract. The engine according to tests met the requirements of the specification but would not satisfactorily operate the machine.

The facts of the case are:

1. The application specification was in error. Actually the washing machine needed more than one horsepower to satisfactorily drive it.
2. Manufacturer A was building more into his produce than he was willing to assure through specification.
3. Manufacturer B did make an engine that met the requirements of the specifications and would perform at rating for a satisfactory period of time.

4. The performance requirement for the engine in the equipment specification was clean cut, namely, that of satisfactory operation of the washing machine.
5. Setting forth the requirement only, for procurement, would have introduced a vague and non-standard method of evaluation. Interpretation would have been necessary--a specification must not require interpretation.

The above analogy was very simple in that one application was involved and only one characteristic essential. Most applications of an electron tube are greatly complicated requiring the correlation of many independent and interrelated properties. When attempts are made to procure electron tubes for military purposes with the many and diverse applications that are involved, the "satisfactory operation" approach is impractical due to the economics involved and may even result in no procurement.

In regard to electron tube procurements in the past few years. such situations have happened in varying degrees. In one case a manufacturer had economic need to produce an electron tube, much more reliable than any existing, for a special application. The methods employed were somewhat peculiar to that manufacturer (no two engineers pursue the same course in solving a problem). A basically careful and expensive quality control was employed throughout the manufacturing processes to accomplish the desired reliability. Raw materials, partially fabricated, or processed materials were inspected with processes corrected and/or lots rejected when nonconforming. Extremely careful supervision was employed throughout. All these items of control were part of the "construction specification." The finished tube specification was quite broad and incomplete. A more specific and detailed specification was not required, as the quality of the product was bonded by the reputation and future of the manufacturer. The customer needed an item to reliably cover his specific need, even though the cost of the item was high.

The success of the application of these tubes was phenomenal. It was desirable to procure similar tubes for the military, hence, the requirement of a military procurement specification. The manufacturer complied, in part, by offering the incomplete finished tube specification under a type number, that, until this time carried considerable magic. (It covered a highly reliable tube encompassing a particular manufacturer's processing.) Competitive bidding was the first step in establishing a source of supply. A second manufacturer was awarded the contract at a price many times less than the originator's. The tubes procured may have been from the regular production of a prototype, but they met the specification. By way of integrity defense the contractor could have maintained that his product was equivalent to the more costly product due to more effective controls within manufacturing. In any event, he met the specification.

From the above may be deduced several things in regard to procurement specifications.

1. The specification sets the limiting conditions and values for acceptance. Any quality better than that limited by specification is gratuitous quality and as such cannot be relied upon from an application standpoint.

2. The type number has no meaning except to identify the specification when related to military procurement.
3. Two types having the same specifications must be expected to be the same in reference to the application.
4. More than one method of processing, or processing control, may yield equal results.
5. Specifying of processes, or process control, may result in incompatibility within the specification.
6. All features concerning a process may not be known; as a consequence many interpretations are possible, some of which are incorrect.
7. Specifying of processes or process controls may place unjust limitations on competition.

## 2. Basic Considerations of Military Control Specifications

Ratings are the limiting values defining each individual operating condition within which the tube type can be expected to yield a normal period of satisfactory service.

Specifications for electron tubes are usually divided into two major parts:

1. A section containing information primarily for use by equipment designers and manufacturers, including the ratings and mechanical structural features.
2. A section containing the properties required of the tube, with test conditions and limits by which compliance with the ratings are to be ascertained.

Many specifications in the past have neither set forth clearly defined requirements nor included such tests as may be necessary to determine compliance with the requirements given. Military control specifications include clearly defined requirements and whatever tests as are necessary to determine desired compliance.

Care must always be exercised that the ratings are of definite value to both the equipment designer and the tube designer, that they can be evaluated by test, and that they do not impose non-intended limitations on the use of the item. An example of questionable rating is the use of a definite altitude, such as 10,000 feet absolute maximum as a rating. This failed to aid the equipment designer as no clear-cut limitations were in evidence. Was the altitude, as stated, the limiting condition or was the pressure or temperature to be considered? If the designer enclosed the circuit in a box and pressurized the environment of the tube to an equivalent altitude below 10,000 feet, could such a unit be used above 10,000 feet? What tests could be imposed on the tube to determine the compliance with this rating?

Military control specifications require a definite purpose for each rating. In the above-mentioned case of attribute rating an investigation was necessary to ascertain the real purpose of the test. This investigation revealed that altitude had little effect, but rather that ratings depended upon the conditions associated with increased altitude, namely:

1. Pressure was reduced as altitude increased, thereby reducing the breakdown voltages between external leads.
2. The reduced pressure afforded less convection cooling usually resulting in a higher operating temperature of the tube at the same power input. This operating temperature could be affected by many other environmental conditions, therefore other means of rating had to be used. From the temperature standpoint the simplest and most complete item to be specified was bulb temperature. Bulb temperature was found to be an applicable rating for all environmental conditions from a thermal standpoint.

A summary of an analysis of the altitude rating problem is as follows:

1. Pressure affected the breakdown voltages between the external connections of the electron tube. This condition can be evaluated directly by a test and is useful to the equipment designer, as he can de-rate for high altitude.
2. Bulb temperature was affected by reduced pressure; however, other environmental conditions affected this temperature. As a rating, bulb temperature had to be an independent item and could be used directly by the equipment designer.
3. The altitude rating imposed a non-intended limit on the application.
4. A pressure voltage breakdown test was specified on all military control specifications.
5. Bulb temperature, usually specified, became a requirement on all military control specifications.

The fundamental purpose of military control specifications is to assure that the product procured meets the ratings. No assurance can be given in regard to a rating unless there is included a test for satisfactory operation under conditions of the rating. All ratings of military control specifications must have a corresponding test for compliance. Let us assume that a tube has a maximum rated bulb temperature of 200°C, but that no test is required with bulb temperatures in excess of 100°C. No assurance can be given that any given tubes procured will operate at all under conditions of 200°C. If a rating of 200°C exists, and a test is specified requiring a bulb temperature of 200°C, but the bulb temperature during 1000 hours life testing is 100°C, and if after the life test the tube satisfactorily passes the test, the only assurance is that tubes can be operated continuously for 1000 hours at 100°C bulb temperature and instantaneously at 200°C.



Another area oftentimes presenting a false impression of assurance of compliance with ratings is that of specifying only an initial test for a property greatly affected by the detrimental effects of exposure to maximum ratings for prolonged periods of time (life test). An example presently appearing on many specifications is the insulation between the elements referred to as "electrode insulation." In the majority of cases the only measurement specified is for initial acceptance testing. When this value is quite high as compared with other specifications, the user assumes a feeling of security, although it is a fallacy to do so, and may select a tube so defined for a critical application. This type of test is a gratuitous test freely given without any measure of value. Many properties of the structural materials of the tube, some difficult to control, may cause an extremely rapid decrease of this resistance during operation. Assurance of continued operation can only be given when a test is made that reveals these properties, or a process or construction specification exists that adequately controls all factors contributing to the problem. A test still must be used to determine whether or not the presumed control of the process is factual.

## PART II

### TEST AND TEST METHODS FOR INCLUSION IN MILITARY SPECIFICATIONS

#### A. General Considerations of Test and Test Methods

As a result of the need for more reliable operation of electron tubes, more attention is being given to the "detrimental properties." These are inherent properties of an electron tube that are detrimental to circuit operation. Circuit design and/or degree of assurance of reliable operation must be modified as a result of the presence of these detriments. The difficulties of satisfactory application assurances are increased by (1) the very diverse environmental conditions of the application and (2) inadequate and incomplete tests for many of these detriments. Each equipment design engineer, confronted with the specific requirements of his project, rightfully defends his tube requirements and associated tests when the vagueness of the existing specification precludes satisfactory assurance of circuit performance.

The military control program has been introduced to systematize the approach to reliability by establishing a uniform method for electron tube description through tests, particularly from the point of view of the equipment designer and the ultimate user. To achieve this objective, several areas are covered:

1. Methods of investigating application requirements. Reference here should be made to WADC Technical Report 53-479, "Electron Tube Specification Design in the Field of Vibration and Impact Shock," by R. Radeloff. Although the title implies restriction, it is equally applicable to any environmental requirement or a combination of all such required properties.
2. Specifying the requirements and associated compliance tests, MIL-E-1 Specification. This is the area of major concern in this report, therefore an elaboration of this phase will follow.

3. Interpretation of electron tube properties, reference: "Techniques for Application of Electron Tubes in Military Equipment." "The specific purpose of this manual is to provide the equipment designer with a better knowledge of the nature of tubes, their capabilities, characteristics, and limitations, the effects of environment on tube operation, and methods of dealing with tube properties in circuit design, so that he may produce equipment which will provide the Services a full return in efficiency and reliability of electronic equipment." (Quoted from 1st Lt. A. B. Bishop, Minutes at Second Guided Missile Conference, 16-17 June 1953).

## B. Organization of Military Control Specification Acceptance Tests

Specifications mentioned in paragraph 2 have been standardized as to format and methods of evaluation. Such standardization greatly assists in the comparison of electron tubes from an application evaluation standpoint. Fig. 1 shows the organization of these acceptance tests.

The two main divisions are (1) measurement tests and (2) degradation rate tests. It is essential for evaluation that these two items be kept separate, at least in the mind of the specification designer. Measurement tests are, as the name implies, for the purpose of determining the instantaneous values of a measurable property. Degradation rate tests are for the purpose of determining rate that a property is adversely affected by a given environment. This involves time and the change of value during that time. Rate is always the amount of change divided by the desired time ( $\text{rate} = \text{value}/\text{time}$ ).

All tests are degrading to some extent. Each time a tube is operated, it has removed from its potential life the time of such operation. This statement in no way implies that tubes cannot be improved by some operation. It merely states that time has been consumed and with time a portion of the potential life. The problem is to ascertain what this operation has done to the tube and its useful life. No clearly-defined boundary can be ascribed to these tests except as determined by the fundamental purposes intended by performing the test. An example is vibration testing. A tube is inserted into the test equipment and subjected to the mechanical stimulus. A measurement made at any time is a result of a condition at that instant. The tube is continued in this environment for a time, then another measurement is made. The second measurement, when compared with the initial measurement, serves to determine the amount of degradation. The present vibration test specified in Specification MIL-E-1B paragraph 4.9.19.1 is an example of an attempt to establish a measurement test under conditions that are known to be essentially degrading. This reads, "Unless otherwise specified, each tube shall be vibrated for a time necessary to obtain a stable reading of output voltage or for a maximum period of 30 seconds in any one position." Had the specification read, "Each tube shall be vibrated for such time as is necessary to obtain a stable output reading," it would have been a poorly-defined degradation rate test rather than somewhat of a measurement test. The rate would have been based on any time to reach stability or to go outside the limits.



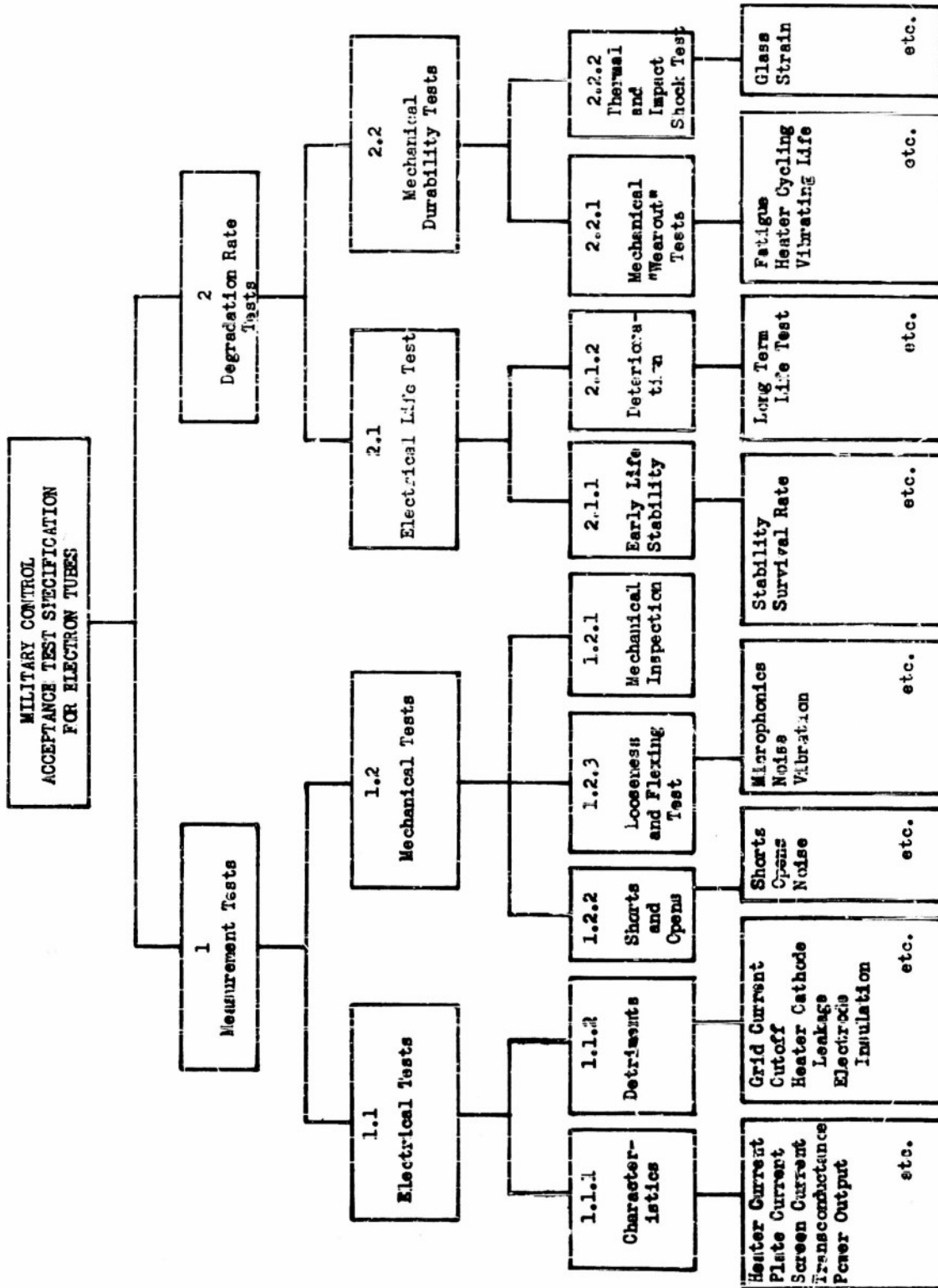


Figure 1. Military Control Acceptance Test Specification for Electron Tubes

## 1. Measurement Tests

Measurement tests fall into two rather distinct categories, namely, electrical tests and mechanical tests. A large number of the mechanical tests use an electrical indication for measurements. This is done for simplicity and is not to be confused with the test itself. It is much easier to determine that two parts come into contact (short) by electrical means rather than to attempt to observe such a contact. In general, mechanical tests are for those properties that act as detriments when the tube is subjected to a mechanical stimulus (dead shorts and discontinuities excepted).

Electrical characteristics are those properties of an electron tube essential to the operation of the circuit and usually are the properties on which the fundamental circuit design is based. All other measurement tests are for detriments to fundamental circuit operation causing modification of either the circuit or the assured reliability of the circuit.

Characteristics usually require modifications in circuit design when they are permitted to vary too greatly from the design center value. Economics and supply are usually the limiting factors on the circuit designer. In instances where a large number of tubes are used or where special circuit considerations are required, it is desirable not only to maintain the characteristics within limit but also to control the product toward the bogey (design center) value. Such centering controls should be used only for characteristics or other properties having highly repeatable measured values. All properties permitting evaluation only as good or bad should have the bad eliminated from the product. An example is plate current cutoff. Normal variations in manufacturing procedure results in a variation from the design centers. However, the limits ascribed are usually many times that to be expected from the design. These limits are to reveal the effects of badly distorted grids due to poor workmanship.

## 2. Degradation Rate Tests

The most important item in regard to the application of electron tubes (and other devices) is the ability to perform satisfactorily under application environmental conditions. This satisfactory performance, from the standpoint of the Air Force, has as a minimum the duration of a mission. Very careful consideration must be given the tests used to estimate the lasting qualities of electron tubes. This method of approach in military control specifications is to divide the degradation rate testing into two basic groups: (1) electrical life test and (2) mechanical durability test.

### (a) Electrical Life Test

The electrical life test usually is associated with the actual electrical operation of tubes. These tests are not always separable from mechanical life tests, but the distinction should be maintained as well as possible. Due to the multiplicity of applications, a better evaluation usually results when the effects of the tests are not intertwined. As an example, it is very difficult to evaluate the true emission life when life-tested under vibration condition. On the other hand, intermittent life test incorporating (MIL-E-1B paragraph 4.7.5) heater cycling serves two satisfactory purposes: (1) it reveals this inherent ability of the tube to withstand normal switching application from an emission standpoint, and (2) it permits a mechanical test on the filament during heater cycling.

## (b) Mechanical Durability Test

The mechanical durability test determines the degrading effects of mechanical stimulus applied to the tubes. This may be in the form of an acceleration, or a thermal shock test. Included in the first group are vibration and impact shock; in the second group are glass strain tests, heater cycling, etc.

## C. Evaluation of Test Results

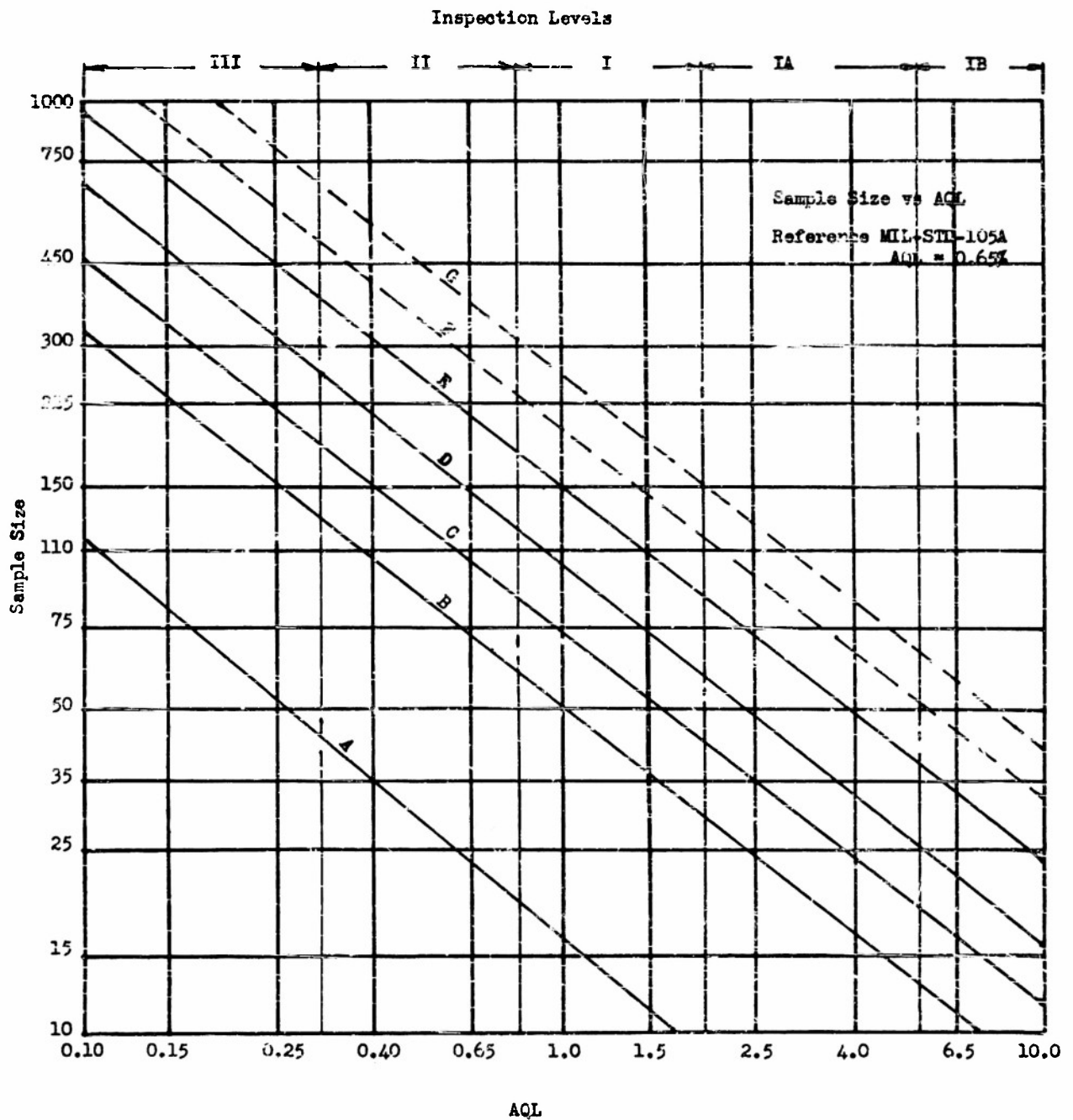
Military control specifications require acceptance by sampling. This does not in any way preclude the use, or even the requirement, of testing 100 per cent of the lot for certain test items. If a testing of 100 per cent of the lot is specified, acceptance should then be on the basis that the sample size is 100 per cent of the lot. This is to say that a given maximum percentage of defects must be ascribed to the acceptance test. If this acceptance percentage is exceeded, the lot is not acceptable irrespective of the fact that the lot has been presumably screened 100 per cent by virtue of the test.

Specification MIL-STD-105 will be used for acceptance sampling. However, for shock test, MIL-E-1, paragraph 4.9.20.5 will be used; for heater cycling, MIL-E-1, paragraph 4.11.4; and for life test, 20 tubes first sample and 40 tubes second sample. There is no fixed assignment of inspection levels in MIL-STD-105. Due to the range of acceptable quality level (AQL) values used in electron tube specifications, a single inspection level is impractical. For military control specifications the inspection level will be related to the AQL value as shown in Fig. 2.

In addition to standardizing inspection levels, Fig. 2 establishes a fixed ratio between the AQL value and fraction defective in the lot for all values of AQL and probabilities of acceptance.

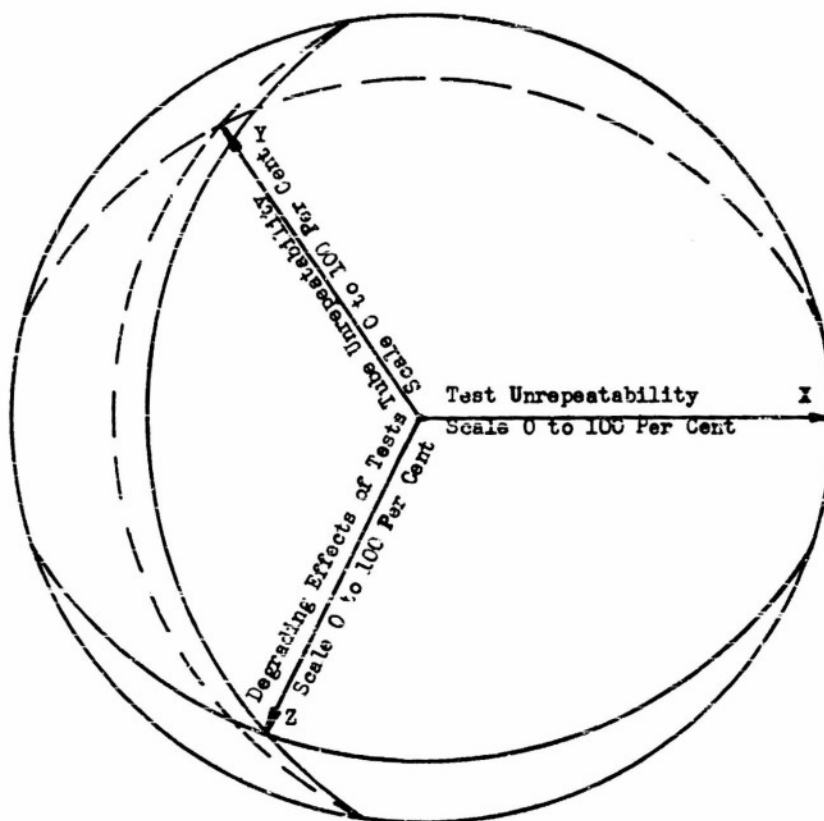
As indicated in previous discussions all tests have at least three components that can be shown as in Fig. 3. This is a three-dimensional diagram of three ever present influences on the effectiveness of measurement testing. If all three are at the origin, or common center, it would be possible to effect a perfect screening operation. Unfortunately, all three are not at zero and the amount of deviation can only be determined by test. To determine exactly the specific components or combination of components that deviate from the center and the degree of deviation would be quite a project in many instances. It is usually sufficient to know that the factors are not at the center.

Any one of these components (X, Y, or Z) deviating from the center makes it impossible to test a lot and know its true character after such testing. All that can be said is that screening removed a given percentage of defects that were in the lot. Many examples can be cited covering all three axes. A good one is noise testing. Much difficulty is experienced in giving the tube under test the same acceleration each time. This is represented by component Y, test on repeatability. Loose particles, lint, etc., make tube repeatability impossible. This is component X, tube unrepeatability. Repeated tapping changes the looseness factor, the rate depending upon the severity of tapping. This is represented by component Z, degrading effects of the test. In the case of noise testing, little additional could be gained by 100 per cent testing rather than sample testing. When any components of Fig. 3 deviate from the center by a considerable amount, the best that can be done is to know what is in the lot as testing will assuredly not eliminate the defects (see Fig. 4).



	Ac No.	Lot Size	$P_a @ AQL$
A	0	2-300	74.1
B	1	301-800	91.3
C	2	801-1300	96.3
D	3	1301-3200	98.3
E	4	3201-8000	98.5
F	5	8001-22000	98.5
G	6	22001-110000	98.5

Figure 2. Relation of Acceptable Quality Levels to Sample Size and Inspection Levels



$$\text{Test Ineffectiveness} = 100 - (100 - X)(100 - Y)(100 - Z)$$

Figure 3. Sphere of Test Ineffectiveness

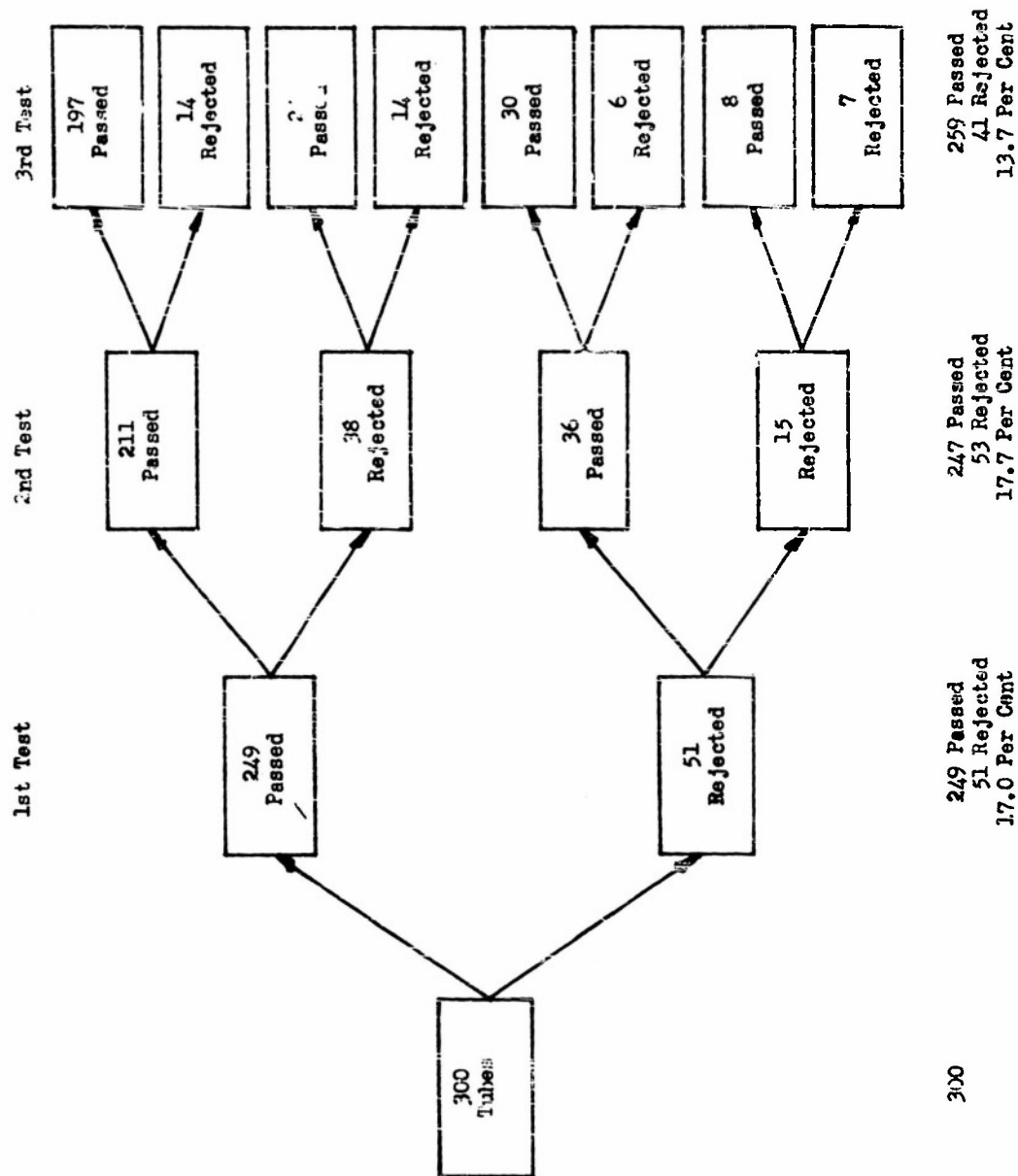


Figure 4. Test Efficiencies

## 1. Effectiveness of Testing

When the position of Fig. 3 is not known, it is well to consider the economics of testing by looking at a set of operating characteristics (OC curves) of a sampling plan. See Fig. 5. These curves show the probability of acceptance of a lot in per cent, vertical axis, when the lot quality is as shown on the horizontal axis. As can be seen, very little can be gained in assurance above the sample size of 15 per cent of the lot. If the tests employed were known to be perfect, that is, at the origin of Fig. 3, a 100 per cent screening test would remove the defectives, but in order to know this the test must be performed more than once on the same lot and repeated for each lot. An example is the data accumulated from noise testing a lot of tubes. As a defective was found during the test, it was marked but not removed from the lot. The results of such a test are shown in Fig. 4. In this case the test was less than 50 per cent repeatable. All the factors contributing to non-repeatability were not known; however, a sample of relatively small percentage would have revealed the nature of the lot for all practical purposes at a considerable saving of manpower and time. True in this case, the defectives are high, but it still remains that it was necessary to check by a retest to note the effectiveness of the test.

Many attempts have been made to improve an electron tube by burning and/or vibrating, then testing. Unfortunately, in most instances no attempt was made to determine test effectiveness. In some cases testing alone would yield approximately the same results. Preliminary tests performed by WADC regarding tubes burned, vibrated, and tested only, at Gentile and Kelly Depots show that the effectiveness of the test is very poor. As a result of such poor effectiveness of testing, the effects of many degrading tests have been obscured or misinterpreted.

A demonstration test was set up to simulate the difficulty due to non-repeatability of tubes, tests, and degrading effects of tests. Instead of tubes, which would require a considerable amount of equipment not suitable for a lecture room, wooden beads were used. The test was outlined into five steps. The purpose of the test was to determine when the tested product contained all white beads. The test procedure was to allow the beads to fall into the recesses in a paddle that was just deep enough to expose one-half the bead. The beads in the paddle were examined visually. The tests were arranged as follows:

1. All white beads.
2. Mostly all white beads, some all back mixed in.
3. Mostly all white beads, some with a black dot mixed in.
4. Mostly all white beads, some with a black dot mixed in; all the lot coated with powdery white material that would abrade in handling.
5. A mixture of all beads to simulate actual practice.

Fifty positions were on the paddle that was run through the beads and the holes filled. Tests were by visual observation. Results are as follows:

- Test 1. The operator was not appraised of the nature of the lot. When none was revealed in the first test run, he performed the test again.

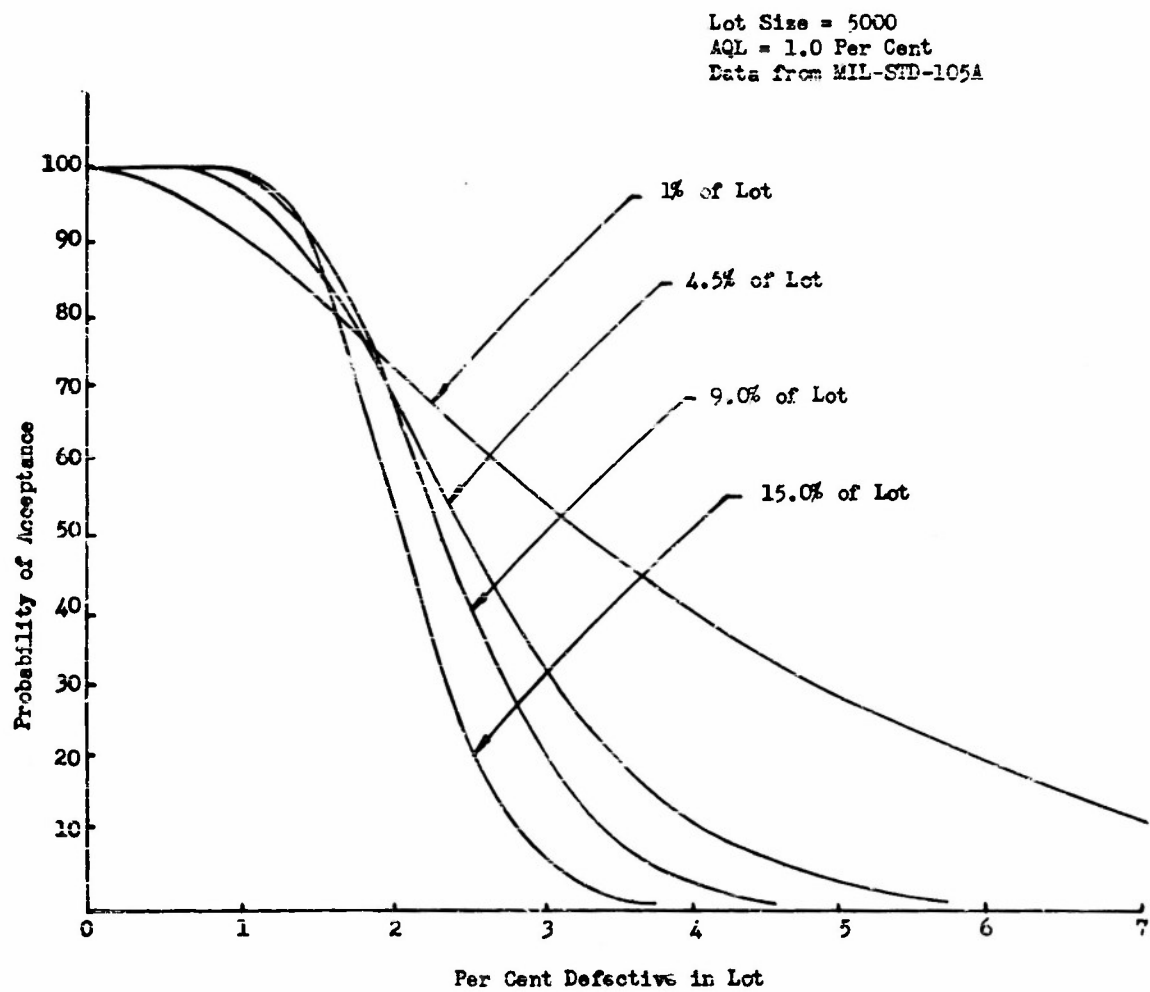


Figure 5. Operating Characteristic Curves



Test 2. The operator assumed no mixing of the unrevealed defects.

Test 3. Five hundred beads were used in this test; 100 had small black dots on them (readily seen). A complete test was the inspection of the entire 5000. Those discovered with black dots were removed. The objectives of the test were twofold: (1) to remove all with dots from the lot and (2) to determine the point at which assurance could be given that the defects remaining in the lot were less than 0.25 per cent. To get sampling data, six random paddles full of beads were selected.

The results of the tests were good; however, the operator questioned the results and made a check test for his own assurance. No difficulty was encountered as the operator felt that the tests revealed all the defects. Tabulated results follow:

<u>Test</u>	<u>100 Per Cent Screening</u>		<u>Per Cent Defective</u>	<u>Sample (300) 0.25 AQL</u>	
	<u>Defects</u>	<u>Per Cent</u>	<u>Remaining</u>	<u>Defects</u>	<u>Action</u>
1	48	.96	1.04	6	reject
2	20	.40	.64	4	reject
3	9	.18	.46	0	accept
4	9	.18	.28	2	accept
5	4	.08	.20	1	accept
6	3	.06	.14	1	accept
7	1	.02	.12	0	accept
8	2	.04	.08	0	accept
9	2	.04	.04	0	accept
10	0	.00	.04	0	accept
11	1	.02	.02	1	accept
12	1	.04	.00	0	accept

Inspection of the results shows that a 0.25 per cent AQL sampling plan accepted the lot when the true amount of defectives remaining were 0.46 per cent. The efficiency of the test was 50 per cent. (See Fig. 2 Component X). The defectives remaining were indicated as less than 0.25 per cent.

No data were compiled or recorded when performing this test. However, the more testing, the more coating was removed thereby revealing defects. This was an illustration of degrading effects of the test. Assuming the coating powdered off and covered the dot at times but dusted off other times, the conditions of component Y would have been illustrated.

The combination of all would have been more nearly typical of electron tubes.

In the preceding, the "defectives" of the lot were known, so the actual percentages could be readily established at each step. In practice the defectives of the lot must be estimated on the basis of test results, with no definite values assigned unless more than one test is performed and effectiveness evaluation is attempted. Referring to the tabulated results, a serious error would have been made if it had been assumed that the first screening test had removed all defectives and further tests had been discontinued. An examination of the results indicates a 55 to 60 per cent efficiency of the tests. This actually is not too greatly in error.

The sampling test results coincided well with the test results of 100 per cent testing. The lot was not acceptable until the quality, as indicated by the test, was below the required limit as revealed by the test. If a sample only had been taken after the first 100 per cent screening test, the results would have shown non-acceptability. Further testing would have been necessary.

Any single 100 per cent screening test tells what was found in the lot, but in itself does not assure that all defectives have been removed from the lot. Sampling tests on the other hand are all based on what is in the lot, therefore can be used for quality level estimation. Even when the sample is 100 per cent of the lot, acceptance should be on the basis of the defects found.

Diagrammatically 100 per cent screening can be related to sample inspections as in Fig. 6. In this figure it is assumed that the AQL is 0.65 per cent, the defectives in the original lot are 10 per cent, and the efficiency of test is 50 per cent. The number of tubes in the first lot was 2000, and MIL-STD-105 tables, inspection level II, were used for the sample. The diagram should be self-explanatory.

## 2. Gratuitous Tests

Many existing specifications include items that are impossible to evaluate in terms of any application requirement. These can be termed "gratuitous tests," as they appear to offer something over and above the actual requirements. However, such tests contribute little to the value of the specification itself. Many times these gratuitous tests are actually a part of the particular manufacturer's "construction" specification. Two examples of items of the gratuitous nature are (1) electrode insulation (initial only) and (2) "burn-in" or "stabilization." Many others of similar nature exist.

Electrode insulation becomes a gratuitous test when it is specified as an initial acceptance test but is not evaluated on life test. The effects of continued burning on properties of this nature has been discussed previously. Such a listing "gives" something additional but without any maintenance responsibilities on the part of the supplier. Where continued performance is an objective, circuits cannot be designed around the values of such properties, for maintenance is not assured.

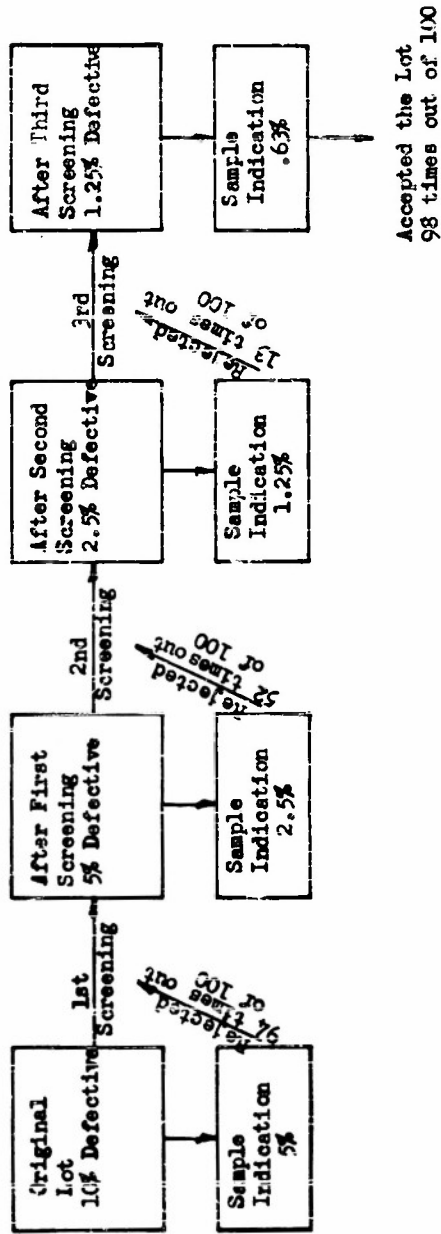


Figure 6. Relation of Screening Tests to Sampling Tests

"Burn-in" or "stabilization" is, as the name implies, an act whereby the product is subjected to a process rather than to any form of a test. The basic principle of the military control program requires that the desired results of the process be included in the specification but not the process itself. That is to say, it is necessary to know what benefits are to be derived from a test and also to know how to measure these benefits. When it is desirable to be assured of the results of such a process, an item is added to the specification defining the desired results as acceptance criteria. A listing of such a process only on the specification sheet is binding on the supplier only to the extent that he performs the operation; the results are not considered. In such a case it appears that considerable is offered but actually no assurances are given.

In some of the more recent MIL-E-1 specification sheets listing the process or stabilizing, an attempt was made to rectify the major discrepancy by adding limitations to the allowable defectives from the lot after such processing. This approach failed to meet the objectives of the military control program in that the use of a processing method limited the ingenuity of the individual manufacturers. Additionally, the tests showed what was in the product rather than an estimate of the existing quality level.

#### D. Control by Variables

Two methods of control are used in military control specifications. One is by attributes and the other by variables. The important difference between the two is that acceptance by attributes controls individual compliance to a set of limits, whereas acceptance by variables controls the distribution of the individuals. In a large number of cases the two are used together, but they may be used separately. An example relative to electron tubes is plate current. Usually end limits are established to cause rejection of any individuals that fall outside these limits. An additional test may be specified to control the distribution of the individuals within these limits. The first is known as controls by attributes and the latter, controls by variables. When controls by variables are not used, the distribution of the product may assume any configuration. The majority may be near one or both limits resulting from severe screening, or the individuals may be rather uniformly distributed throughout the range resulting from poor controls and screening at both ends. A distribution of individuals of a product having normal controls of processing applied (no attribute rejection limits included) is as shown in Fig. 7. This is called a curve of "normal" distribution. Usually in practice the boundaries extend further toward the plus (+) side, a feature referred to as "skewness."

##### 1. Considerations for Variables Testing

Electron tubes are designed to attain a certain set of electrical characteristics. Usually the design also includes certain mechanical considerations that aid in the control of the undesirable properties. If it were possible to manufacture the item without deviation from the design data, the resulting tubes would all be according to design figures. However, it is not possible to produce a group of items without some deviation from the specified value. The extent of this deviation is dependent upon the inherent difficulty of maintenance of the design and the effort applied to maintain the design features. Control of these variables are limited by economics of the manufacturing operations. It may appear economically

Areas from  $\infty$   
Equivalent to AQL Values

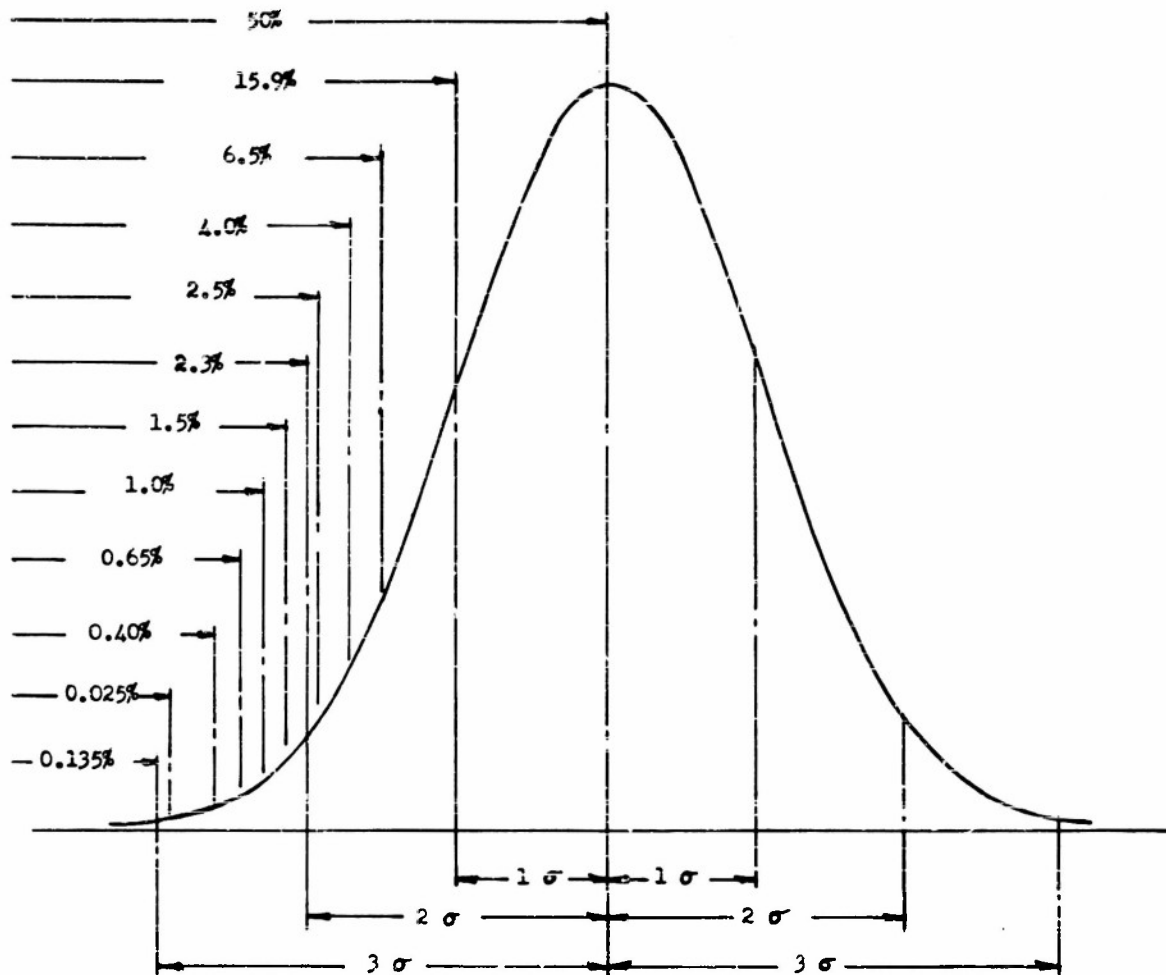


Figure 7. Normal Distribution Curve

impractical to improve the characteristics due to many factors based on the individual manufacturer's methods or equipment; however, this must not be considered as inherent in tube manufacture. Such limitations may be the result of outdated equipment or similar conditions.

These electrical characteristics vary around the design center value (bogey) according to an approximately uniform pattern referred to statistically as a "normal" distribution. The width of this distribution is dependent on those items that vary "normally" in the process of manufacture. Associated with these variations are always the "bungled" type of defect. An example of the difference is plate current cutoff when referred to the grid voltage. The design results in a cutoff of a certain center value of grid voltage. The actual voltage required will vary due to many items, such as uniformity of grid wire, the variation of grid size, and many others that vary about the center value. (See Curve A, Fig. 6.) Some tubes will have grids badly distorted due to careless handling. The latter case will appear as a "maverick" and does not fit the pattern of the remainder of the product. (Notice the long tail.) Usually "plate current" cutoff is specified as a certain maximum plate current at a grid voltage condition greater than required to reduce the design center tube to zero plate current. The test, then, is one for mavericks. As a result the majority show zero as the cutoff figure, the magnitude of the other measurements depending upon the extent of the maltreatment of the grid. Such a distribution is usually referred to as "J" shaped.

Properties occurring in J-shaped distribution are usually undesirable properties and can be referred to as detriments. That is, the circuit designer must make allowances in the circuit design for the presence of such properties.

A large portion of the properties that must be controlled by the specifications are of the undesirable nature, for example, electrode insulation, heater cathode leakage, vibration output, etc. For the purposes of military control specifications variables controls are not applied to detriments as the desire is to always reduce the effect toward zero as much as possible. The limits alone will control the product if properly established. See Fig. 8. For effective control the cutoff voltage should be reduced materially.

## 2. Limits for Variables Control

Military control specifications are constructed on the basic principle that quality cannot be tested into a product. For this reason the attribute limits are intended for the elimination of maverick rather than for purposes of good screening from a lot containing both good and bad. To achieve this desired control and to devise the proper specification is a joint responsibility of the tube manufacturer and the equipment manufacturer.

1. The equipment designer establishes the electron tube requirements for his circuit. A tube is useless without the associated circuitry.
2. When the circuit requirement exceeds the economical limits of tube manufacturing, a modification is necessary to procure the tube.

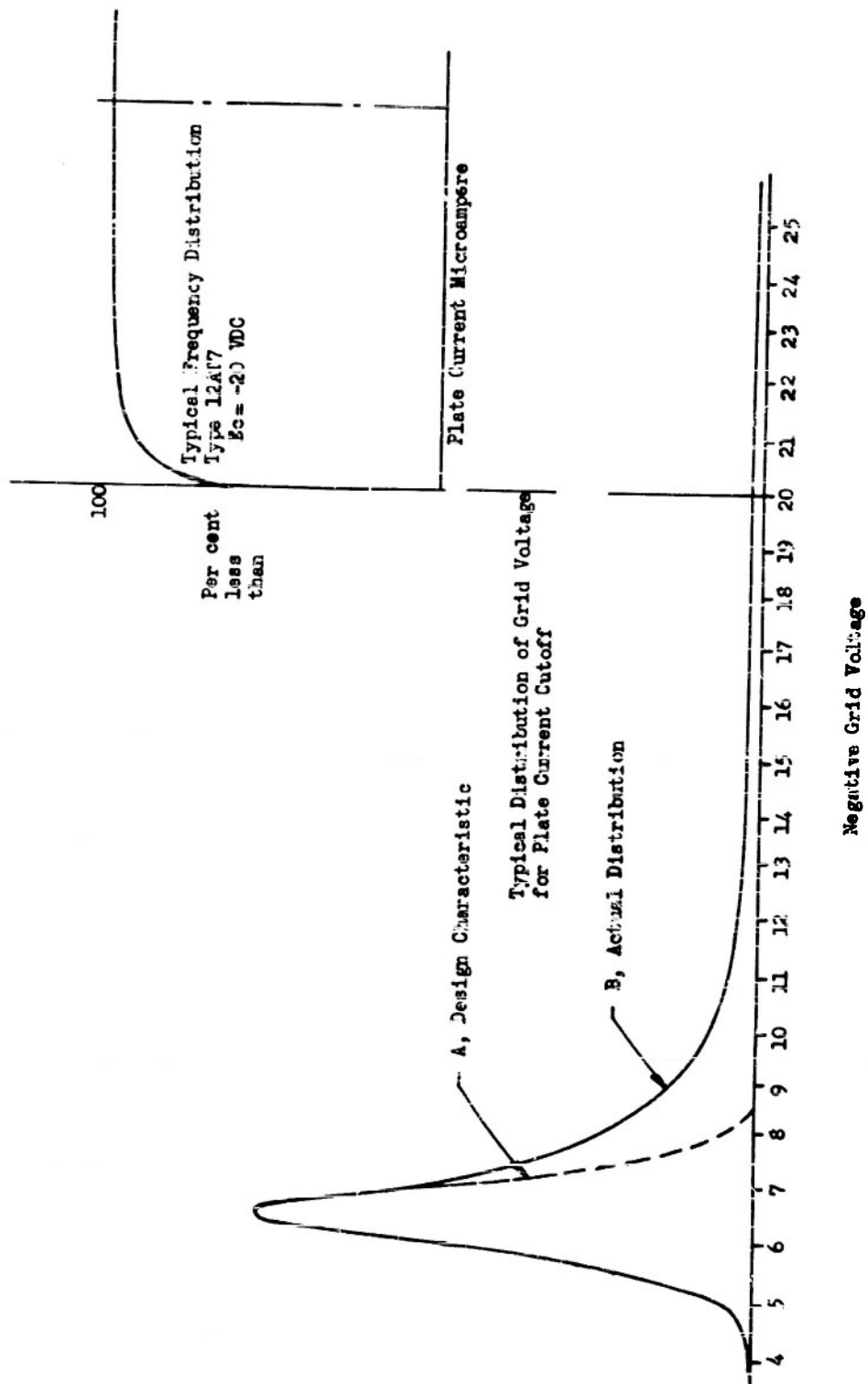


Figure 3. Typical Distribution of Grid Voltage for Plate Current Cutoff

Many factors are involved in establishing both the real requirements from the equipment designer standpoint and the true economical level of quality from the tube manufacturer's standpoint. Slight modifications of either the circuitry or tube manufacturing processes may result in an entirely different electron tube-circuit relation. Many examples of either can be cited, but it is sufficient to say that if the circuit requires limits that are economically too tight for the tube industry, the limits must be broadened. If no way can be found by which the circuitry can be modified, more effort must be applied to tube manufacturing controls.

The generally accepted variation of the average of a product due to manufacturing tolerances is about one standard deviation ( $\sigma$ ) of the product (see Figs. 7 and 9). This variation is rather independent of the width of the distribution. As an example, a product made with a greatly improved control has a much more limited spread of characteristics, and likewise the spread of the averages of various lots is proportionally reduced. This will undoubtedly change when electron tube assembly and processing becomes more mechanized. A machine could be quite precise in maintaining an inaccurate setting. Throughout the military control specifications the permissible shift of the average from center is one standard deviation. All distributions are assumed to be normal or nearly so. If the distribution is skewed, the (bogey not in center) side closer to the center is assumed to be "normal" (see Fig. 10).

Figure 9 illustrates the distributions of a product showing the limit of the averages only. When attribute limits (go - nogo) are assigned, such limits are placed at a point that the excluded area under the curve (one side) is equal to the AQL ascribed. This is represented by area "A", Fig. 10. The distribution curve on which the limits are based are from one of two sources:

1. Actual distribution of the product.
2. Limits required for the application.

The relation of the limits and the AQL values are as shown in Fig. 10.

- A = AQL value = area excluded from under normal curve (from  $\infty$ ).
- D = Distribution of items of the lot.
- D<sub>1</sub> = Distribution of averages of samples from lot. This distribution will vary according to number of items in the sample.
- A<sub>1</sub> = Area excluded from under curve = 5 per cent
- $\sigma$  = Standard deviation of product.
- $s\sigma$  = Sampling error.

$$z = \frac{1.65}{\sqrt{N}} \quad \text{where } N = \text{sample size}$$

$x\sigma$  = Distance from center (mode) to point at which area excluded from under curve = AQL (given in standard deviations).

$y$  = An empirical distance from mode to point at which excluded area = AQL.

#### (a) Setting of Limits from Product Data

Limits established from a product as shown in distribution curve Fig. 10 follow: (only one lot is shown).



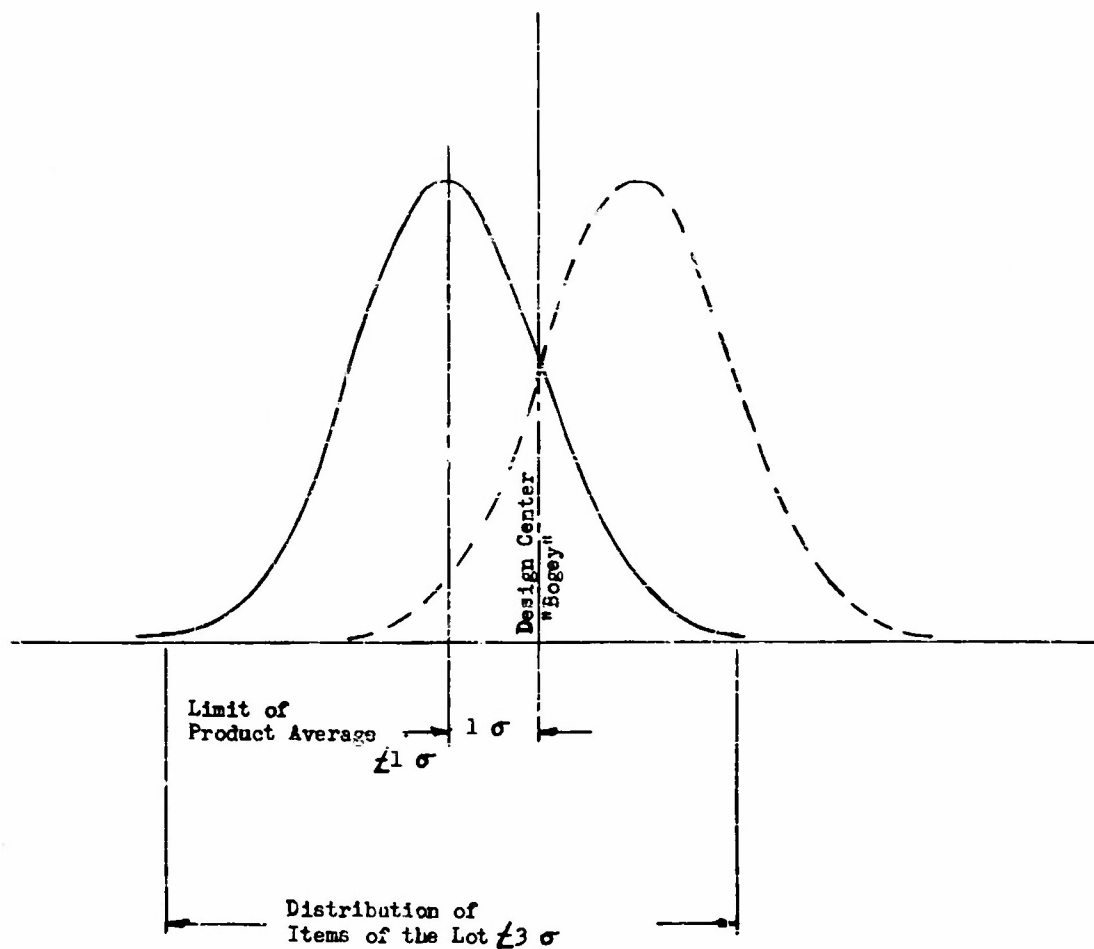


Figure 9. Relation of Product Shift to Design Center

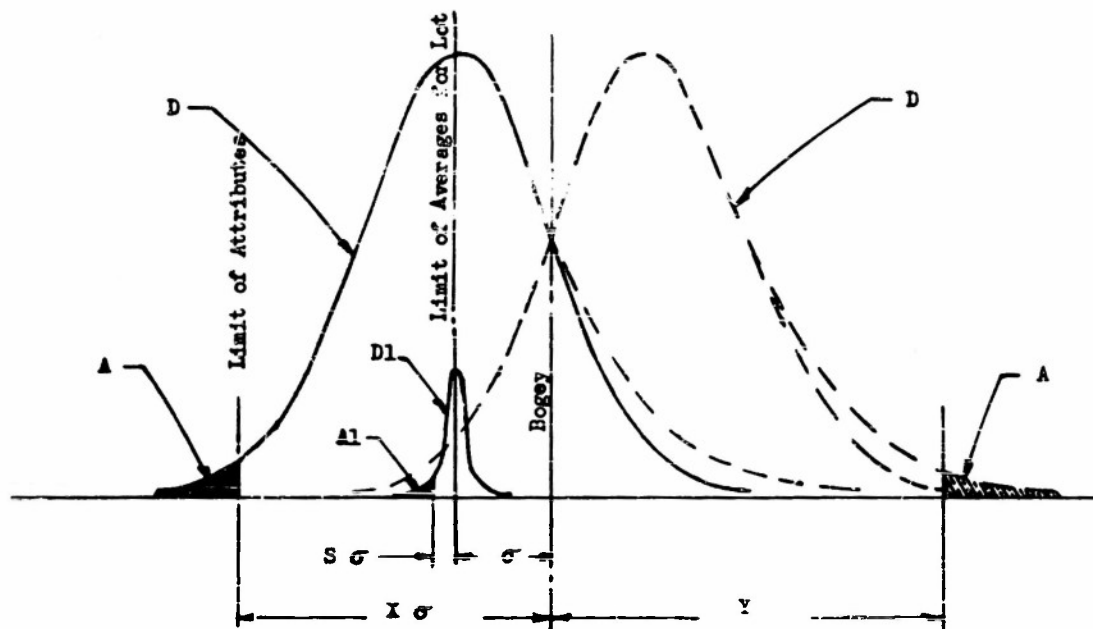


Figure 10. Relation of Sampling Methods to Specification Limits

1. For symmetrical distribution:

- a. Acceptance limits for sample average =  $\text{Bogey} \pm (\sigma + s\sigma) = \text{UAL}^*$  and  $\text{LAL}^{**}$
- b. Acceptance limits for attributes =  $\text{Bogey} \pm (\sigma + x\sigma) = \text{MAX}$  and  $\text{MIN}$ .

2. For skewed distribution (skewed to high side):

- a. Acceptance limits for sample average =  $\text{Bogey} \pm (\sigma + s\sigma) = \text{UAL}$  and  $\text{LAL}$ .
- b. Lower acceptance limit for attributes =  $\text{Bogey} - (\sigma + x\sigma) = \text{MIN}$ .
- c. Upper acceptance limit for attributes =  $\text{Bogey} + (\sigma + y) = \text{MAX}$ .

3. For skewed distribution (skewed to low side):

- a. Acceptance limits for sample average =  $\text{Bogey} \pm (\sigma + s\sigma) = \text{UAL}$  and  $\text{LAL}$ .
- b. Lower acceptance limits for attributes =  $\text{Bogey} - (\sigma + y) = \text{MIN}$ .
- c. Upper acceptance limits for attributes =  $\text{Bogey} + (\sigma + x\sigma) = \text{MAX}$ .

As the preceding example is based on actual production experience, it should be the basis of limit setting for new developments. In these cases the economical limit can be established for combination of the application and the tube manufacturer.

(b) Setting of Limits for Lot Average or Median When Attribute Limits (and AQL) are Given

When limits have been established and the AQL values which set the procedure used for establishing acceptance limits for sample average are based on these limits, provided that the theoretical distribution is as shown in Fig. 10, it is assumed that:

- 1. The portion of the distribution curve in the region between the bogey and the closer attribute limit is "normal."
- 2. The distance between bogey and the closer attribute limit is equal to one standard deviation " $\sigma$ " plus the number of units of standard deviation determined by the AQL (see Fig. 7).
- 3. Limits not symmetrical about bogey are to allow for skewness of the product.

\*Upper acceptance limits.

\*\*Lower acceptance limits.

Using these assumptions (reference Fig. 10), the acceptance limits for sample average (or median) = Bogey  $\pm$  ( $\sigma \div s\sigma$ ).

Example:

$$\begin{aligned}\text{Bogey} &= 32.0 & \text{AQL} &= 0.65 \text{ (} x = 2.4 \text{)} \\ \text{MIN} &= 24.0 & \text{MAX} &= 42 & \text{Sample} &= 35 \text{ (} s = 0.28 \text{)} \\ \text{Bogey} - \text{MIN} &= X \sigma + \sigma \\ \sigma &= \frac{\text{Bogey} - \text{MIN}}{X + 1}\end{aligned}$$

Low acceptance limit for average of sample

$$\begin{aligned}\text{LAL} &= \text{Bogey} - \left( \frac{1 + s}{1 + x} \right) (\text{Bogey} - \text{MIN}) \\ &= 32 - \frac{1 + .28}{1 + 2.4} (32 - 24) \\ &= 32 - 3.02 \\ &= 28.98 \\ \text{UAL} &= 32 + \frac{(1 + .28)}{(1 + 2.4)} (32 - 24) \\ &= 32 + 3.02 \\ &= 35.02\end{aligned}$$

Tables for determining limit need only the tabulation of  $\frac{1 + s}{1 + x}$ . The value of  $s = \frac{1.65}{\sqrt{N}}$ , and "x" can be found in any tables of "areas under the normal curve." The excluded area is equal to the AQL. For the usual values of AQL values "x" is as follows:

AQL	x
0.25	2.81
0.40	2.65
0.65	2.49
1.0	2.33
1.5	2.17
2.5	1.96
4.0	1.75
6.5	1.51

### (c) Limits for Lot Dispersion

The foregoing method of control of distribution applies to single lots. Although the system is based on a product approximating normal distributions, acceptance criterion is an average (or a median). This average would permit the mixing of a lot having a high average with one of low average to make an acceptable average. In order that this be prevented a test for lot "dispersion" is introduced. The purpose is to prevent mixing of out-of-limit lots to make an acceptable lot.

Two methods are satisfactory for checking acceptable dispersion. One is graphically apparent. This method is accomplished by counting the items of measurements outside the acceptance limits for sample averages. When these measurements are less than half the measurements of the sample, the lot is considered acceptable.

The other method requires the establishment of an acceptance limit for sample dispersion (ALD) and a sampling check for compliance. A limit for averages does not depend on the nature of the distributions. Any limit for dispersion, however, depends considerably on the nature of the distribution. Limits used in military control specifications for acceptable lot dispersion are computed in that the probability of acceptance is 99.9 per cent for a lot having a standardization equal to " $\sigma$ " and a normal distribution. When determining the probability of acceptance of a lot for any single property, the limits for averages, dispersion, and attributes must be considered. This value is expanded by the factor of 1.33 to allow for the acceptance of a grand lot made of two acceptable normal distributions on upper and lower limits for averages, see Fig. 10 (according to Mr. Herrold, Sylvania Electric Products).

When computing the acceptance limit for dispersion

Where  $ALD = k \sigma$

$k$  = a factor dependent on number of units in each sub-group and the number of sub-groups. (For military control all sub-groups = 5 units).

A check for compliance to ALD is made by determining the average of the ranges of sub-groups.

Range of sub-group =  $R = (\text{Maximum} - \text{Minimum})$

The dispersion of the sample ( $\bar{R}$ ) is the average range of the sub-groups. It will be computed by totaling the range of the sub-group and dividing by the number of sub-groups ( $m$ ).

$$\text{Dispersion } (\bar{R}) = \frac{R_1 + R_2 + \dots + R_m}{m}$$

When the dispersion so established is equal to or less than ALD, the lot is acceptable for dispersion.

Two methods for determining dispersion are alternates and yield equivalent results from a practical standpoint. Slight statistical differences do exist but economics of manufacturing make the effects negligible.

## E. Degradation Rate Tests

The control of initial characteristics is necessary for interchangeability, but no assurance of operation is afforded by this alone. Continued operation of equipment is dependent upon the maintenance of characteristics when subjected to operating conditions. It is then necessary to check all requirements (rating) of the tube on life test as no assurance can be given without such a check. For these reasons, careful consideration must be given the life test of military control specifications. All life tests are for the purpose of determining compliance of the product with the limits of degradation during the time of life test. Therefore, life test should be considered a degradation rate test.

All items are evaluated on a rate basis. That is, a given number of defects that are allowed in the time given. This procedure differs from the method of evaluating life test in most specifications but has the distinct advantage of being able to effectively ascribe an AQL to the various life test end points.

The system of "realized life" tends to emphasize early life failures, but it suppresses the importance of failures toward the end of life. All life test end points are given the same weight unless a complicated system is employed. When an equipment is depended upon, failure is equally as serious when the tube fails between 450 and 500 as when it fails between 0 and 50 hours rate-time. Establishing allowable defects per sample on life tests, equivalent to assigning an AQL value, makes possible a very simple method of establishing assurance of operation in equipment. When additional items require life test, control end limits for such an item can be added to procure the best tube possible for those conditions.

Life test end point limits are established to give assurance to the greatest possible range of application. To accomplish such an evaluation the inclusion of many end point limits are required, whereas probably only a few are required for each application. It must be recognized that the results of this system are generally pessimistic. For more accurate estimation of assurance, the results based on individual items of test, correlated with the application, should be used.

Military control specifications establish the format and the system for life test evaluation allowing freedom in ascribing the various acceptance criteria depending upon the relative reliability of the tube. The following are some of the standardized methods and AQL's:

1. All intermittent life test items shall have individual acceptance numbers (except averages).
2. A fixed sample size shall be used for intermittent life test as indicated on the specification sheet. When co-ordinated, a MIL-STD-105 code letter should be specified (an AQL for acceptance numbers). This will allow for single or double sampling.
3. A total number of allowable defects, or an over-all AQL, is to be assigned to the test items (on present specifications this applies only to 500-hour limits).
4. No acceptance number shall be less than one.

## 1. Electrical Life Tests

Electrical life tests are divided into the following major groups:

1. Stability life test.
2. Survival life test.
3. Intermittent life test.
4. Special life test.

### (a) Stability Life Test

The stability life test is performed for a period of one hour to denote the stability of the electrical characteristics. This is distinctly a test for stability and as such differs from the "stabilizing" process that has been heretofore specified in many instances. Experience indicates that electron tubes show the greatest instability of characteristics in the first period of operation. The rate of change of characteristics is usually greatest in the first hour of operation. In the many instances a restoration takes place after one or more hours. It is the intent of the stability life test to reveal the maximum of this instability and not to continue the test to stabilize the sample. The product must be stable to be acceptable.

### (b) Survival Rate Life Test

The survival rate life test is performed for a period of 100 hours to denote the rate of occurrences of mechanical (and electrical when specified) weaknesses. This life test is to establish the mechanical qualities of the lot. The condition of operation can be less exacting than the long term life test. The less exacting conditions plus the fact that this life test is not considered destructive makes it economical to life test large quantities of tubes thereby realizing a better estimation of the mechanical failure rate inherent to the lot.

Some previous specifications have included the "stabilizing" process as a control of mechanical difficulties. The assumption was that all defects were discovered at test. Many investigations have shown this not to be the case. Assurance of resulting quality could only be attempted by assigning a limit to allowable defects. (Refer to Fig. 4.) Little could be gained by the 100 per cent test from a quality standpoint, as this process would preclude subsequent evaluation. A test for failure rate is included in military control specifications. An individual manufacturer's improved technique of testing may yield more than any process that could be assigned.

### (c) Intermittent Life Test

The intermittent life test is conducted on a smaller number of tubes for a longer period than stability life test. The samples are selected from stability life test so that they are representative of a product acceptable from the standpoint of stability. The two life tests are interrelated; therefore, nothing can be ascertained from starting with tubes unacceptable from the stability standpoint.

It is very important that the most adverse conditions of the ratings apply during this life test. Usually the following are considered as the most adverse of the ratings:

1. Maximum rated electrode dissipations at the maximum voltage conditions.
2. Maximum rated heater cathode voltages.
3. Maximum rated bulb temperature.

The maximum rated bulb temperature is specifically used on life test in place of "ambient" temperature as used in the past. Ambient temperature has meaning when referenced to an electron tube operation, provided an explanation of all conditions is made. A satisfactory ambient temperature is one resulting in the desired bulb temperature (as determined by the investigation at the University of Dayton). Specifying a well-defined ambient temperature would be to specify one manufacturer's procedure, thereby probably stifling ingenuity on the part of other suppliers. Bulb temperature as a condition of operation yields the desired results without method limitation.

The items of test for end of life must be carefully considered in the light of the application. No assurance of continued operation can be given unless a test for the item is made during life test. On tests where correlation exists, for example, plate current, screen current, and transconductance, the inclusion of all is a check on instrumentations and not rightfully a part of life test evaluation. However, a test of electrode insulation, in addition to grid current, should be included if control of the property is desired, as the resistance indicated by the grid current limit is usually very much less than the desired level of insulation.

#### (d) Special Life Test

Special life tests may be required from time to time as the maximum rated conditions alone will not completely assure operation. An example would be a special life test for the detection of cathode-interface resistance development. Such life tests require a separate sample and should be operated under conditions necessary for revealing the properties for which the test is conducted.

## 2. Mechanical Durability Tests

Mechanical durability tests are any tests that depend in whole, or in part, on the application at environmental conditions creating mechanical stresses and strains in the tube under test. These tests as applied to military control are as follows:

1. Fatigue.
2. Shock.
3. Glass Strain.
4. Heater Cycling.



(a) Fatigue Test

The fatigue test is a prolonged vibration test used to determine the resistance of an electron tube to mechanical stimuli. Present fatigue testing is done according to Specification MIL-E-1, paragraph 4.9.20.6; however, any special vibration life test should be considered as a fatigue test. In the event that a low as well as a high acceleration vibration test is desirable, the high acceleration test shall be used in place of the referenced MIL-E-1 fatigue test and the low acceleration test shall be used in place of the survival rate life test. The purpose of fatigue testing must always be to note the rate of mechanical degradation of the electron, in a vibrational environment.

(b) Shock Test

The shock testing is for the effects of impact shock usually of relatively high accelerations for short-time intervals. Essentially the difference between shock testing and fatigue testing is the method of application of the acceleration. No confusion should exist when specifying these two tests. Fatigue test is for the purpose of determining the rate of degradation, whereas shock test assures that a low rate is not achieved at the expense of brittleness and other structural weaknesses.

(c) Glass Strain Test

Glass is quite weak when subjected to certain strains. The most usual form of such strains results from rapid temperature changes especially when there is applied a stress as may be experienced in a socket. The purpose of the glass strain test is to assure that a low failure rate will be experienced in the application. Presently the tests specified apply a rate of change of temperature much greater than experienced in practice. As a result the failure rate permissible for acceptance purposes is many times greater than anticipated in practice.

(d) Heater Cycling Test

Most applications require extensive intermittent operation of the electronic equipment. Each time the equipment is switched on the filament or heater increases in temperature quite rapidly. As a result there is a rapid increase in length, although small. When the heater does not heat uniformly, a considerable amount of deformation occurs that in turn places the heater under considerable mechanical stress. A result of such stresses is the failure of heater cathode insulation and continuity failure of the heater. The effect of heater cycling becomes more evident as the diameter of the heater is reduced. Such diameter is a function of the heater current.

A separate test for regular intermittent life is performed with heater-cycling as the number of cycles required would extend the time of the regular life test until it would fail as an acceptance test.

During intermittent life test the heaters are de-energized 12 to 25 times per 24 hours. The minimum, 12 times, indicates the weaknesses of heaters in the sizes of .300A and above: as a consequence tubes having heater currents in this range are excluded from the test.

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